THE DESIGN AND IMPLEMENTATION OF DRAPER'S EARTH PHENOMENA OBSERVING SYSTEM (EPOS)

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ABSTRACT

Current Earth observation systems trade coverage and revisit times against the number and measurement sensitivity of satellites and on-board sensors. The coverage and utility of observations these large satellites provide are restricted by their selected orbit, launch time, and bus reliability. To lower development and operations costs, a recently proposed alternative is to develop and launch a large suite of smaller size satellites that perform single-purpose measurements.

We present initial results from algorithms developed for autonomous reconfiguration of large numbers of Earth observation satellites made possible in a future world wherein refueling of satellites and/or launching of new satellites is cost effective. The algorithms will reduce requirements on the human operators of such a system of satellites, improve system resource utilization, and provide the capability to dynamically respond to temporal terrestrial phenomena. Our initial system model consists of small numbers of satellites, a single point of interest on Earth (e.g., hurricane) with the objective to maximize the total coverage of the target during a number of orbits. An integrated approach using integer programming, network optimization and astrodynamics was used to calculate integrated observation and maneuver plans that maximize the total coverage of the target while adhering to fuel constraints.

I. INTRODUCTION

"...Thus far, we are only experimenting with long term weather, climate, and natural hazard prediction. The quest for a true predictive capability for Earth system changes requires a flexible and progressive space system architecture that is responsive to our needs based on our current understanding of the system as well as accommodating emerging needs in the coming decades. We need to design and establish a smart, autonomous and flexible constellation [of] Earth observing satellites which can be reconfigured based on the contemporary scientific problems at hand. Such a constellation would exploit a combination of active and passive sensing sensors in ways that we can perhaps imagine today....."

This is a quote from the remarks of NASA Administrator Daniel S. Goldin "The Frontier of Possibilities" presented at the International Astronautical Federation on October 3, 2000. It clearly describes the underlying rationale for the multi-year project in which we are developing algorithms for resource allocation via autonomous reconfiguration of satellite webs consisting of heterogeneous Earth observation sensor platforms.

The development of these algorithms and a simulation testbed in which they reside, the Earth Phenomena Observing System (EPOS), will reduce requirements on the human operators of satellites, improve system resource utilization, and provide the capability to dynamically respond to temporal terrestrial phenomena. Examples of triggering events are localized transient phenomena that have a significant impact on human life such as volcanic eruptions, algae plumes, large ocean vortices, ice shelf break-up, seismic activities, oil spills, magnetic anomalies, weather (tornadoes, hurricanes, etc.), and search and rescue

II. PROBLEM AND APPROACH

Our initial system model consists of small numbers of satellites, a single point of interest on Earth (e.g., volcano, hurricane) with the objective to maximize the total coverage of the target during a fixed number of orbits, e.g., over the course of a week. An integrated approach using integer programming, network optimization and astrodynamics was used to calculate integrated observation and maneuver plans that maximize the total coverage of the target during the fixed time interval while adhering to fuel constraints.

In order to make the optimization problem tractable, we used hierarchical decomposition both temporally and functionally. The decomposition is characterized by higher levels that create plans with the greatest temporal scope (longest planning horizon) but with the least detail. At lower levels, the planning horizon becomes shorter (nearer term), but the level of detail of planned activities increases. The less detailed plans at the higher levels coordinate or guide the generation of solutions generated at the lower levels. Indeed, planning actions over extended periods of time at a high level of detail is typically both futile and impractical. Futile because detailed actions planned on the basis of a specific prediction of the future may become obsolete well before they are to be executed due to an inability to accurately predict the future. Impractical because the computational resources required to develop detailed plans over extended periods of time may be prohibitive either in cost or availability or both. The relationship between the levels of the hierarchy and the planning horizon and level of plan detail is shown in Fig. 1.

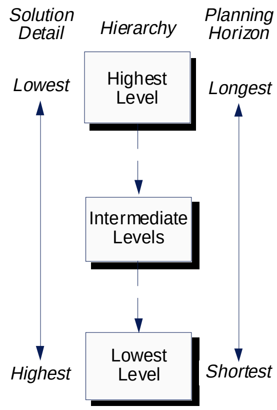

Fig. 1: Temporal decomposition

One way of grouping the types of decisions that need to be made for EPOS is shown in Fig. 2. Three decision tiers are present: 1) the top tier focuses on decisions that impact the entire EPOS (e.g., which targets to collect data for); 2) the middle tier addresses issues that relate to a group of multiple satellites being used to collect data on a target (e.g., which satellites make up this group); and 3) the lowest tier addresses decisions relevant to the individual satellites making up each collaborative group (e.g., what burns should be executed to achieve a certain level of required coverage). This decomposition is natural for satellite operations.

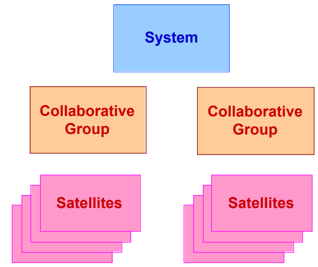

Fig. 2: Three Tiered EPOS Hierarchy

Another decomposition, one based around seven key levels of decision-making is shown in Table 1. The longer term, EPOS-wide issues are determined at the upper levels, while shorter-term decisions are lower down in the list. This is a decision-centric approach to decomposition compared with the entity-centric approach of the three tiers. Note that the description of the decision levels shown in Table 1 presents the capabilities of a complete EPOS system, including functionality that has not yet been implemented.

The three tier and seven decision level hierarchical decompositions can be viewed in a common context as shown in Fig. 3.

TABLE 1: DECISION LEVELS IN EPOS

Decision Level	Decisions
1 system decisions	Select locations on Earth for observation; for each location being observed: what are the candidate satellite platforms?
2 configuration decisions	Which satellites need to be refueled? Which satellites need to be launched?
3 platform assignment decisions	Which satellites are to be actually used for observation?
4 observation decisions	For each satellite, when and for what target should the sensors be used?
5 maneuver decisions	For each satellite, when and with what Δv should the maneuvers be made?
6 sensor decisions	For each sensor, when and in which direction should it be pointed?
7 data and communication decisions	For each satellite, what data to store when, and what data to communicate when?

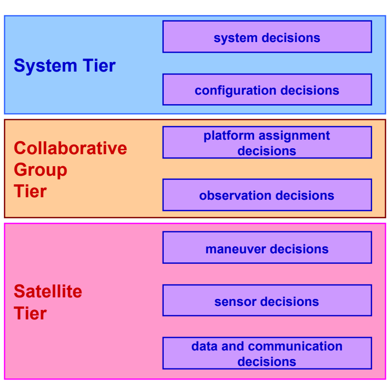

Fig. 3: Mapping of Decision Levels to Tiers

In providing the functional decomposition of EPOS, we utilize Draper's closed-loop planning and execution architecture depicted in Fig. 4 which has been applied to a variety of autonomous systems. It provides a useful perspective for thinking about what is required of an "autonomous system" and why it is so difficult to achieve in practical applications. A system that is truly autonomous must have the capability to perceive, reason and act to achieve desired ends in a resource constrained, dynamic, and uncertain environment, with limited human intervention.

The current implementation of EPOS (version 0.5) is focused on the maneuver decisions and observation decisions. Those two levels will be the focus of this paper.

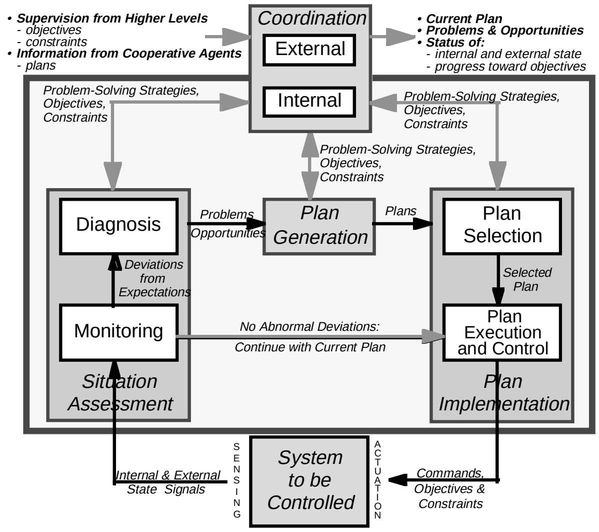

Fig.4: Functional Decomposition

III. Maneuver Planning

In the development of the maneuver planner, the following assumptions were made:

1. Satellites are in near-circular repeat-groundtrack orbits of constant inclination.
2. J_2 secular effects are sufficient to model orbit nodal period and ascending node rate during coast phases
3. We control a satellite by adjusting its orbit nodal period. Adjustments are made using Hohmann transfers (pairs of impulsive along-track burns performed one half rev apart).
4. Period adjustments are performed at most once per rev, at a fixed argument of latitude.
5. Only transfers which result in certain pre-specified circular repeat groundtrack orbits are admissible.

To each satellite we associate a finite directed graph. Vertices in this graph are called states; edges are admissible state transitions. Each edge is labeled with a nonnegative real number ("cost") and an r-tuple of real numbers ("benefit").

Techniques for finding shortest paths in networks may then be applied to problems of satellite positioning.

A. Specification of States and State Transitions

The state set is a finite subset X of $S^1 \times Q^+$, (cartesian product of the circle with the positive rational numbers). The coordinates ϑ and τ of state $x = (\vartheta \quad \tau)$ are sub-satellite longitude and satellite orbit period, respectively. The state is recorded once per rev when argument of latitude equals u_0.

Period $\tau = \frac{n}{d}$ is interpreted as "n days for d revs". Landsat 7, for example, has orbit period 16/233. "Period" is understood to mean nodal period, and "day" is understood to be one revolution of the earth as seen from the orbit plane (accounts for regression of the node). Thus each orbit period specifies a particular repeat groundtrack.

The set of admissible state transitions includes at least the coasting transitions. Suppose that longitude is measured in earth revs, i.e., in *days* (view ϑ as a real number mod 1). Then a coasting transition is a transition of the form

$$(\vartheta \quad \tau) \rightarrow (\vartheta - \tau \quad \tau) \tag{1}$$

The set of admissible state transitions will generally include burn (maneuver) transitions as well as coasting transitions. A burn transition is a transition of the form

$$(\vartheta \quad \tau) \rightarrow (\vartheta - h(\tau,\tau') \quad \tau') \tag{2}$$

where the orbit periods τ and τ' are different and $h(\tau,\tau')$ is the average period (in an appropriate sense) for the rev in which a burn pair is performed to transition from period τ to period τ'.

Every admissible state transition is either a coasting transition or a burn transition.

B. Determining Radius for Circular Orbit of Specified Repeat Groundtrack

The orbit semimajor axis a needed to achieve a specified repeat groundtrack is uniquely determined once orbit inclination $\imath$ and eccentricity e are specified.

Suppose a repeat groundtrack orbit of period $\tau = \frac{n}{d}$ (notations as above) is required. Let r_e denote the radius of the earth (6378.137 km), μ denote the gravitational coefficient (398600.44 km^3/s^2), ω_e denote the earth rotation rate ($7.29211585 \times 10^{-5}$ radian/s) and J_2 denote the second zonal harmonic coefficient (0.00108263).

The rate of regression of the ascending node is given by [1]

$$\dot{\Omega} = -\frac{3}{2}\sqrt{\frac{\mu}{r_e^3}}J_2\left(\frac{r_e}{a}\right)^{3.5}\left(1-e^2\right)^{-2}\cos(i) \tag{3}$$

The nodal period of Greenwich is then [1]

$$T_G = \frac{2\pi}{\omega_e - \dot{\Omega}} \tag{4}$$

Finally, the <u>nodal period of the satellite</u> is [1]

$$T_s = 2\pi\sqrt{\frac{a^3}{\mu}}\left[1 - \frac{3}{2}J_2\left(\frac{r_e}{a}\right)^2\left(3 - 4\sin^2(i)\right)\right] \tag{5}$$

For fixed e and i, both T_G and T_s may be viewed as functions of a.

The semimajor axis required for repeat $\tau = \frac{n}{d}$ is that value of a for which

$$\tau\, T_G = T_s \tag{6}$$

The value of a which satisfies equation 6 for a circular orbit ($e = 0$) will be denoted $r(\tau)$ in what follows. (The notation hides the dependence on i, but i is assumed to be known and constant.)

C. Determining the Cost of a Transition

The cost of a coasting transition is zero.

The cost of the general transition of expression 2 is the delta-v for the two-burn transfer which changes period from τ to τ'. This is computed using the following expressions:

$$\Delta v_1 = \mu^{1/2}\left|\left(\frac{2}{r(\tau)} - \frac{1}{a(\tau,\tau')}\right)^{1/2} - \left(\frac{1}{r(\tau)}\right)^{1/2}\right| \tag{7}$$

$$\Delta v_2 = \mu^{1/2}\left|\left(\frac{1}{r(\tau')}\right)^{1/2} - \left(\frac{2}{r(\tau)} - \frac{1}{a(\tau,\tau')}\right)^{1/2}\right| \tag{8}$$

$$\Delta v_{tot} = \Delta v_1 + \Delta v_2 \tag{9}$$

Here μ is the gravitational constant (398600.44 km^3/s^2), $r(\tau)$ and $r(\tau')$ are the orbit radii for circular repeat groundtrack orbits of period τ and τ' respectively, and $a(\tau,\tau')$ is the transfer orbit semimajor axis $\frac{1}{2}\left(r(\tau) + r(\tau')\right)$.

Note that cost of a transition depends only on the orbit period component of the initial and final state.

D. Determining the Benefit of a Transition

Benefit associated to a state transition is computed in the following steps:

1. Recover initial satellite orbit elements from the transition initial state $(\vartheta \quad \tau)$. The initial orbit is circular of known inclination i, known argument of latitude u_0, and known groundtrack repeat τ. The orbit elements in an inertial frame whose x axis is in the initial direction of the Greenwich meridian are therefore

$$\begin{aligned}
&a = r(\tau) \\
&e = 0 \\
&i = \text{(its known value)} \\
&\Omega = L - \operatorname{atan2}\left(\cos(i)\sin(u_0),\, \cos(u_0)\right) \\
&\omega = u_0 \\
&M = 0
\end{aligned} \tag{10}$$

2. If the transition is a burn transition, these elements must be modified to account for the first burn. To do this, replace a by the transfer orbit semimajor axis $a(\tau,\tau')$ associated to the state transition and compute e, ω and M as follows:

If $r(\tau) < r(\tau')$,

$$e = 1 - \frac{r(\tau)}{a(\tau,\tau')} \quad , \quad \omega = u_0 \ , \quad M = 0 \tag{11}$$

If $r(\tau) > r(\tau')$,

$$e = \frac{r(\tau)}{a(\tau,\tau')} - 1 \quad , \quad \omega = u_0 - \pi \quad , \quad M = \pi \tag{12}$$

3. Starting with orbit elements from step 1 (coasting) or step 2 (burn), propagate the orbit forward by half a rev, taking suitably short steps. At each step, compute satellite position vector. Also compute the position vector of one or more ground targets (operator-specified latitude and longitude). Compute line-of-sight, look angles, range, etc, from the position vectors and associate incremental benefit by applying metrics as required.

4. If the transition is a burn transition, the propagated orbit elements must now be adjusted to account for the second burn. Only a and e are modified. Put

$$a = r(\tau') \ , \quad e = 0 \tag{13}$$

5. Propagate the orbit forward for the remaining half rev, taking short steps, and computing benefit increments as in step 3.

6. The benefit associated to the transition is the sum of all benefit increments computed in steps 3 and 5.

IV. Observation Planning

The observation planner uses the results of the maneuver planner to plan when a satellite should view a target. The objective of the planner is to maximize total viewing time of a single target.

A. Formulation

The objective function is a function of the way in which the satellite approaches the target. To accommodate this, the state space of the optimization problem will consist of a state that allows for the full set of orbit elements of the satellite to be reconstructed. Specifically, the state is composed of the orbit period of the satellite and the (earth-fixed) longitude of the satellite when its argument of latitude has a specified value. After discretizing the state space, one can consider each possible state to be a node in a graph. The nodes will be connected by edges that specify the delta-v required to transition from one state to another (a zero cost edge would indicate that the satellite would coast to the specified state without any control applied).

To support this formulation, the planning horizon will be specified by the number of orbits to optimize over rather than the number of days. If the planning horizon is N orbits and there are M possible states that the satellite can be in, the graph can be drawn as in Fig. 5.

There are M nodes for each orbit, or MN nodes in total. The node labeled S_0 is the initial state. The node labeled G is a "dummy" goal node for the problem. A path must be found from the initial state to node G.

Each edge has a non-negative cost associated with transitioning from one state to the next. The cost of transitioning from state i to state j is f_{ij}. The edges leading into node G have zero cost.

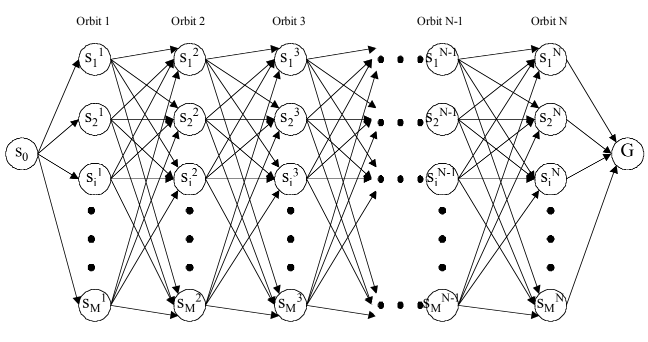

Fig. 5: Network View of State Space

With the exception of S_0 and G, each state has a reward associated with it which is the total time that the target will be in view on the following pass. The reward for state j will be r_j.

The decision variables in the LP will indicate if an edge is being used in the path. Define

$$x_{ijk} = \begin{cases} 1 \text{ if there is flow from state } i \text{ (in orbit } k\text{-1) to state} \\ \quad j \text{ in orbit } k \\ 0 \text{ otherwise} \end{cases}$$

The range of i is 0..M, the range of j is 1..M and the range of k is 1..N. Note that the value i=0 is only valid when k=1. To specify flow to the goal node, define

$$x_{ijG} = \begin{cases} 1 \text{ if there is flow from state } i \text{ (in orbit } N\text{) to state } G \\ 0 \text{ otherwise} \end{cases}$$

The LP is written as:

$$\max \sum_{i=0}^{M}\sum_{j=1}^{M}\sum_{k=1}^{N} r_j x_{ijk}$$

subject to

$$\sum_{j=1}^{M} x_{0j1} = 1$$

$$x_{0i1} - \sum_{j=1}^{M} x_{ij2} = 0 \quad i = 1..M$$

$$\sum_{j=1}^{M} x_{jik} - \sum_{j=1}^{M} x_{ijk+1} = 0 \quad i = 1..M, k = 2..N-1$$

$$\sum_{j=1}^{M} x_{jiN} - x_{iG} = 0 \quad i = 1..M$$

$$\sum_{i=1}^{M} x_{iG} = 1$$

$$\sum_{i=0}^{M}\sum_{j=1}^{M}\sum_{k=1}^{N} f_{ij} x_{ijk} \le F$$

$$x_{ijk} \in \{0,1\}$$

The first five constraints specify network flow constraints. If the fuel consumption constraint were not present, the problem would be a pure network flow problem and can be solved with the network simplex method (or any other LP algorithm) and integer solutions would be guaranteed [2]

The fuel constraint could naturally be relaxed and put into the objective function since it is not a hard constraint in practice. The non-negative Lagrange multiplier, λ, would be used to specify the "cost" of the fuel in the following formulation:

$$\max \sum_{i=0}^{M}\sum_{j=1}^{M}\sum_{k=1}^{N} r_j x_{ijk} - \lambda \sum_{i=0}^{M}\sum_{j=1}^{M}\sum_{k=1}^{N} f_{ij} x_{ijk}$$

subject to

$$\sum_{j=1}^{M} x_{0j1} = 1$$

$$x_{0i1} - \sum_{j=1}^{M} x_{ij2} = 0 \quad \mathrm{i = 1..M}$$

$$\sum_{j=1}^{M} x_{jik} - \sum_{j=1}^{M} x_{ijk+1} = 0 \quad \mathrm{i = 1..M, k = 2..N-1}$$

$$\sum_{j=1}^{M} x_{jiN} - x_{iG} = 0 \quad \mathrm{i = 1..M}$$

$$\sum_{\mathrm{i=1}}^{\mathrm{M}} \mathrm{x_{iG}} = 1$$

$$x_{ijk} \in \{0,1\}$$

The value of λ that is input to the problem specifies the relative value of the fuel. As λ is increased, the fuel is more expensive the problem would tend to use less fuel at the expense of passing up viewing opportunities. If λ is closer to zero, then fuel is not an expensive commodity and the problem would tend to maximize the viewing time without regard to the amount of fuel needed [3]. Efficient data structures can be employed to generate solutions for a range of values of λ so that a viewing time vs. fuel used curve can be generated.

Once the fuel constraint is removed from the formulation, the problem is a pure network shortest path problem (strictly speaking, this formulation is for a longest path problem). Since the graph is acyclic, very efficient algorithms exist to solve the problem [4]. The current implementation of this problem can solve a problem with approximately 10,000 states and 300 orbits in just a few seconds.

It should be noted that to support future work in which the plan will be executed and monitored in real-time, the reward gained from future orbits should be discounted. When changes in the environment are sensed, the problem will be resolved so, in effect, the final orbits in the plan will rarely be executed. If the values of these future orbits were discounted, then the problem would prefer to get value for near term orbits rather than far term ones. The discounting would be as simple as:

$$\max \sum_{k=1}^{N} e^{-\alpha k} \sum_{i=0}^{M}\sum_{j=1}^{M} r_j x_{ijk} - \lambda \sum_{i=0}^{M}\sum_{j=1}^{M}\sum_{k=1}^{N} f_{ij} x_{ijk}$$

subject to

$$\sum_{j=1}^{M} x_{0j1} = 1$$

$$x_{0i1} - \sum_{j=1}^{M} x_{ij2} = 0 \quad \mathrm{i = 1..M}$$

$$\sum_{j=1}^{M} x_{jik} - \sum_{j=1}^{M} x_{ijk+1} = 0 \quad \mathrm{i = 1..M, k = 2..N-1}$$

$$\sum_{j=1}^{M} x_{jiN} - x_{iG} = 0 \quad \mathrm{i = 1..M}$$

$$\sum_{\mathrm{i=1}}^{\mathrm{M}} \mathrm{x_{iG}} = 1$$

$$x_{ijk} \in \{0,1\}$$

where α is the discount rate.

V. Human System Integration

The operator interacts with the EPOS maneuver and observation planning algorithms via a graphical user interface (GUI). The goal in the development of the EPOS GUI was to take the first steps toward understanding the issues of human-system integration for a realistic sized system, e.g., with many satellites and multiple targets. The EPOS system is complex, and one of the primary design objectives of the GUI is to simplify as much as possible the operator's interaction with the system, while still allowing him or her an adequate level of insight and control into the system.

The EPOS GUI divides the system into its constituent tiers: the *system*, *collaborative group*, and *satellite* tiers. The operator can interact with the system at the various tiers by focusing his or her attention on a different part of the GUI window. The GUI is designed to provide the highest tier user interactions (e.g. system tier) at the top of the GUI. The bottom of the GUI provides information about planning at the individual satellite tier.

At each tier, the GUI interfaces the operator to the EPOS planning algorithms. These algorithms aid the operator in performing complex computations and optimal decision making. At the same time, the GUI reduces the amount of information that the operator must input and process by displaying only the most critical data to the operator, and doing so in an intuitive manner.

A. GUI Operations

Initially, the operator manually selects the target and the performance metric (e.g., total viewing time) to be used as the objective for the Observation Planner's optimization. This is the current proxy for the eventual system tier real-time objective "maximize the scientific value of future observations." Based on the latitude and type of the target, the GUI then eliminates satellites which are inappropriate, e.g., inclination or sensor-target infeasibility, and highlights recommended satellites for the operator (Fig. 5).

Once the satellites are selected, the operator then clicks the Calc. Costs button, resulting in a plot of benefit as a function of the amount of fuel used for each satellite. Color coding is used to make it easier for the operator to get an overall picture of the options available. The operator then selects the percentage of fuel to be allotted to each satellite by clicking on the plot in one selected box for each satellite (Fig. 6).

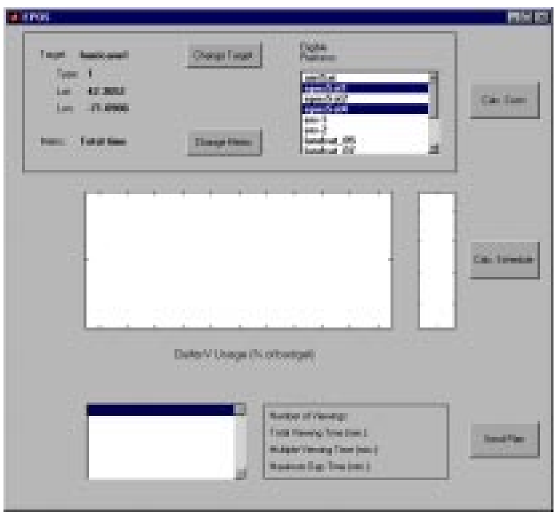

Fig. 5: Select Target and Benefit Metric

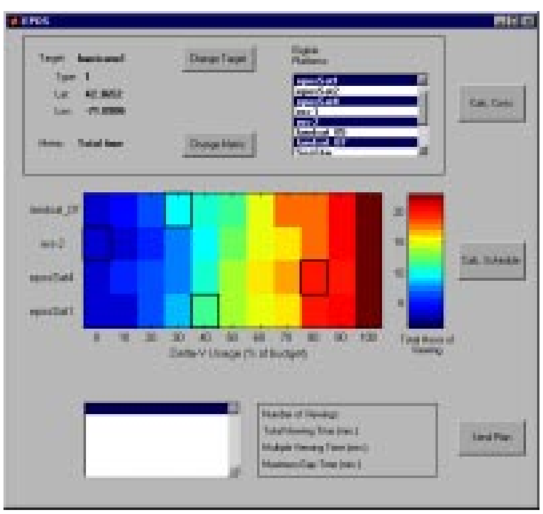

Fig.6: Select Fuel Allotment For Each Satellite

Next, the Calc. Schedule button is clicked and the optimized schedules for each satellite are automatically generated. The operator then manually selects which satellites to task, using Collaborative Tier metric values (number of viewings, total viewing time, multiple viewing time, maximum gap [in coverage] time) provided in the display as a guide (Fig. 7).

After the satellites are selected, the Send Plan button is clicked and the plan is sent to the Satellite Tool Kit® (STK) environment for simulation, display, and evaluation (Fig. 8).

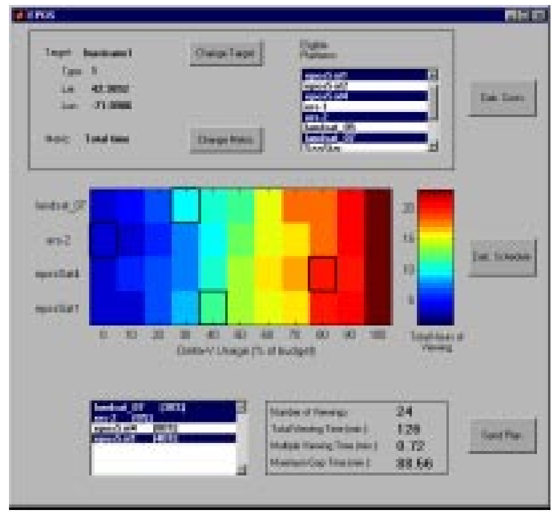

Fig. 7: Select Final Satellites To Be Tasked and View the Resulting Benefit

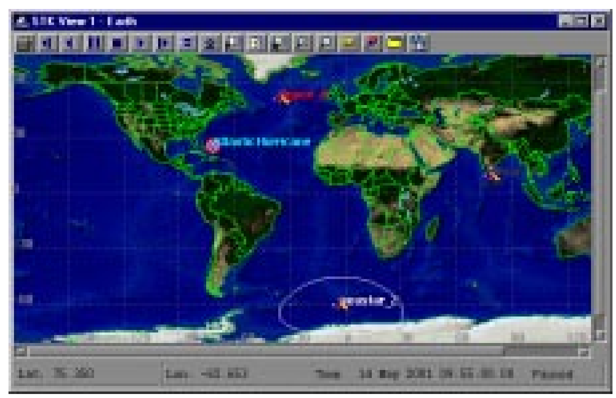

Fig. 8: Plan Sent to STK For Simulation and Visualization

VI. Analysis and Results

EPOS 0.5 is an intermediate build along the way to EPOS 2.0 described briefly in a subsequent section. Nonetheless, we have identified the types of analyses that are feasible to perform with this version of EPOS. Two of the types of results that can be generated with EPOS 0.5 relate to 1) the benefit that can be obtained from a autonomously generated set of observation and maneuver plans and 2) the "costs" that will be incurred by the system if these plans are implemented.

A. Benefit-Related Results

The measured benefit in EPOS 0.5 is an operator-defined metric for the quantity of target observations that are achievable by the system, either measured as total coverage time or number of observations possible. The achievable benefit can be measured as a function of parameters dependant on satellite design, orbital design, satellite operations and target location. This allows the operator to pinpoint the portions of the system that have a critical impact on the observation time that is attainable. For example, the relationship in orbital design parameters like altitude and inclination, and satellite design parameters like sensor ground sweep can be used to aid in the selection of appropriate satellites and orbits that will be maximize viewing opportunities for specific targets. When combining the benefit of possible viewing times for multiple satellites with the sequence of when the viewing times would occur, custom viewing schedules can be created for the operator. For example, the operator can observe how deploying different satellites will create schedules that vary the number of viewing opportunities possible.

B. Cost-Related Critical Results

Costs measured in EPOS 0.5 are defined as the amount of fuel that is used to achieve the desired observation plan. Analysis of the costs incurred by the system to achieve the desired benefit can help the operator identify areas that are not cost effective. Trends relating the viewing time achievable to the amount of fuel required during orbital maneuvering burns can be used to identify benefit to cost ratios with the highest efficiencies.

Additional utility can be obtained by combining information gathered. When analyzing the information on viewing schedules as a function of fuel used for orbital maneuver burns, the operator can observe trends between fuel usage and the type of coverage desired. This information allows the operator to determine if the type of schedule that is desired for observing the target provides a means of achieving an efficiency that will still be flexible enough to satisfy dynamic viewing opportunity needs.

VII. Future Work

Key areas of focus for version 1.0 of EPOS include handling many satellites (>100), handling multiple targets, increased autonomy in the platform assignment decision level, and increased human-system integration.

EPOS 1.0 will extend the capabilities of the EPOS 0.5 demonstration system which focused attention on a single target and small numbers of satellites. Bounding the decision space will be a challenge, as it quickly increases as the system description gets more complex. A second challenge in handling multiple targets will be making the best satellite assignments given all the desired targets. The initial approach will be to treat the targets independently, producing disjoint sets of satellites that will observe each target. This goal will be to relax this independence restriction as soon as possible.

EPOS 1.0 will also extend the capabilities of the EPOS 0.5 demonstration system which required the human to select the platforms to use in viewing the target. Providing the automated decision support capability to aid the operator in selecting platforms and their fuel / opportunity tradeoff in an efficient manner will be a significant challenge.

Version 2.0 of EPOS will focus on introducing real-time closed-loop control. All versions of EPOS through EPOS 1.0 effectively perform pre-mission planning – all targets and resources are considered and a single plan is produced to maximize measures of merit. Version 2.0 will introduce the ability to replan to accommodate new targets once the initial plan is underway. An increased focus on collaborative planning will be part of EPOS 2.0 as well.

Acknowledgments

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